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Additive Manufacturing of Polymer Components by Fused Deposition Modelling: Influence of Process Parameters on Mechanical Strength and Dimensional Accuracy

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ABSTRACT

Fused deposition modelling is among the most accessible additive manufacturing processes and is increasingly used for functional polymer components rather than visual prototypes alone. The mechanical and dimensional quality of printed parts, however, depends strongly on the choice of process parameters. This paper investigates the influence of layer thickness, infill density, and print orientation on the tensile strength and dimensional accuracy of components produced from a common thermoplastic. Standard tensile specimens were printed at several parameter settings and tested, and dimensional deviations were measured against the nominal geometry. The results show that tensile strength increases with infill density and is higher for finer layer thickness, while flat-oriented specimens outperform upright ones because inter-layer bonding governs failure. Dimensional accuracy improves with thinner layers but at the cost of longer build times. The findings provide practical parameter guidance for producing functional fused deposition modelling parts and confirm that strength and accuracy can be tuned, within limits, through informed parameter selection.

KEYWORDS: *Additive Manufacturing, Fused Deposition Modelling, Process Parameters, Tensile Strength, Dimensional Accuracy, Infill Density, Layer Thickness*

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INTRODUCTION

Additive manufacturing builds components layer by layer directly from a digital model, offering geometric freedom and rapid realisation of designs that are difficult to achieve by conventional means. Among the available processes, fused deposition modelling has become especially widespread owing to its low cost, simplicity, and the availability of inexpensive thermoplastic feedstocks (1, 2).

Originally used chiefly for visual prototypes, fused deposition modelling is now applied to functional parts in jigs, fixtures, and end-use products. This shift has raised expectations of mechanical performance and dimensional accuracy, both of which are sensitive to the deposition process and the resulting layered, anisotropic structure (3, 7).

The quality of printed parts depends on numerous parameters, including layer thickness, infill density, print orientation, and printing temperature (4, 6). This paper examines how layer thickness, infill density, and orientation affect tensile strength and dimensional accuracy, with the aim of providing practical guidance for functional applications.

LITERATURE REVIEW

The principles and taxonomy of additive manufacturing are well established, and standard terminology distinguishes the major process families (1, 2, 9). Within fused deposition modelling, research has repeatedly shown that the mechanical properties of printed parts are anisotropic and strongly dependent on build parameters (3, 5).

Investigations of process parameters have identified infill density and layer thickness as major determinants of strength, and orientation as decisive because failure tends to occur along inter-layer interfaces (5, 6). Reviews of materials and methods have further highlighted the role of bonding quality and porosity in governing part performance (7, 8).

PROCESS PARAMETERS AFFECTING PART QUALITY

Synthesising the literature (3, 4, 6), the parameters that most strongly affect the quality of fused deposition modelling parts can be summarised as follows:

- Layer thickness, which affects strength, surface finish, dimensional accuracy, and build time.

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- Infill density, a primary determinant of stiffness and tensile strength.
- Print orientation, which governs the direction of inter-layer interfaces relative to loading.
- Raster and contour width, which influence bonding between deposited roads.
- Nozzle and bed temperature, which affect inter-layer adhesion and warping.

RESEARCH GAP

Although individual parameters have been studied extensively, fewer investigations examine tensile strength and dimensional accuracy together, even though these objectives often respond differently to the same parameter changes. Practical guidance that balances the two is therefore limited.

This study addresses that gap by evaluating the combined effect of layer thickness, infill density, and orientation on both tensile strength and dimensional accuracy for a single thermoplastic.

OBJECTIVES

- To review the process parameters governing the quality of fused deposition modelling parts.
- To print standard tensile specimens at varying layer thickness, infill density, and orientation.
- To measure the tensile strength of the printed specimens.
- To assess dimensional accuracy against the nominal geometry.
- To recommend parameter settings that balance strength, accuracy, and build time.

METHODOLOGY

Standard dumbbell tensile specimens were produced on a desktop fused deposition modelling printer using a common thermoplastic filament. Process parameters were varied in a controlled manner, and the printed specimens were tested mechanically and measured dimensionally to relate quality to the chosen settings (3, 5).

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Material, Equipment, and Specimens

A widely used thermoplastic filament was printed on a calibrated desktop machine, with nozzle and bed temperatures held at manufacturer-recommended values to isolate the effect of the studied parameters. Tensile specimens were prepared in accordance with the relevant standard geometry, and several replicates were printed at each setting (9).

Table 1: Process Parameters and Levels Investigated

Parameter	Levels Investigated
Layer thickness (mm)	0.10, 0.20, 0.30
Infill density (%)	20, 40, 60, 80, 100
Print orientation	Flat, On-edge, Upright
Infill pattern	Rectilinear
Nozzle temperature	Recommended value

Testing and Measurement

Tensile tests were conducted on a universal testing machine at a constant crosshead speed, and the ultimate tensile strength was recorded for each specimen. Dimensional deviation was determined by comparing measured lengths and widths with the nominal values, and all results were averaged over the replicates to reduce scatter (5, 6).

RESULTS AND FINDINGS

The relationship between tensile strength and infill density at two layer thicknesses is shown in Figure 1. Tensile strength increased steadily with infill density and was consistently higher for the finer layer thickness, reflecting the greater number of well-bonded interfaces per unit cross-section (5, 6).

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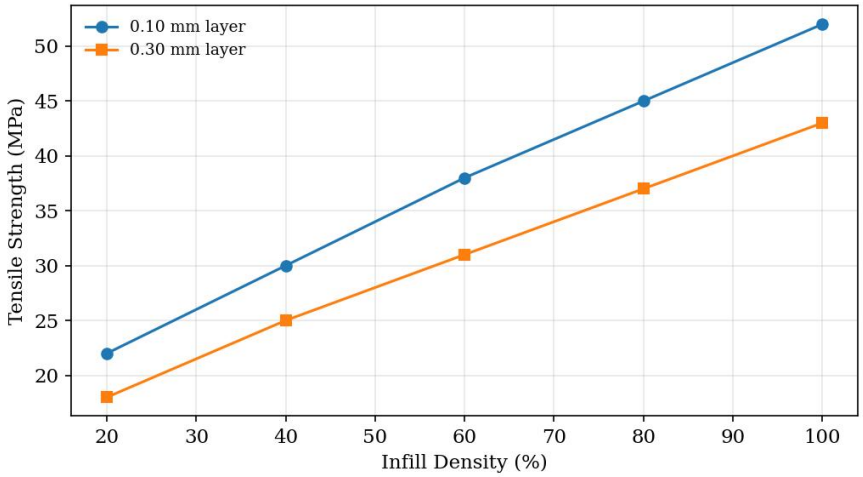


Figure 1: Tensile Strength as a Function of Infill Density for Two Layer Thicknesses

Table 2 summarises the tensile strength and dimensional deviation measured across the parameter settings. Flat specimens were stronger than upright ones for the same parameters, confirming the dominant role of inter-layer bonding, while dimensional deviation decreased with thinner layers. The improvement in accuracy with finer layers was accompanied by a substantial increase in build time.

Table 2: Tensile Strength and Dimensional Deviation at Selected Settings

Layer Thickness (mm)	Infill (%)	Orientation	Tensile Strength (MPa)	Dimensional Deviation (%)
0.10	100	Flat	52	0.25
0.10	60	Flat	38	0.30
0.20	60	Flat	34	0.45
0.30	60	Flat	31	0.60
0.10	100	Upright	39	0.28

DISCUSSION

The results confirm the strong dependence of mechanical performance on build parameters that is characteristic of fused deposition modelling (3, 5). The increase in tensile strength with

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infill density is straightforward, as a denser cross-section carries more load, while the advantage of finer layers reflects improved bonding and reduced porosity between deposited roads (6, 8).

Orientation proved decisive because the inter-layer interface is the weakest link: when these interfaces are aligned perpendicular to the loading direction, as in upright specimens, failure occurs at lower stress (5, 7). This anisotropy must be considered when orienting functional parts so that the principal load is carried within, rather than across, the deposited layers.

Dimensional accuracy improved with thinner layers, consistent with the finer discretisation of the geometry, but the accompanying increase in build time illustrates the trade-off between quality and productivity inherent in the process (4, 6). Parameter selection should therefore reflect the relative importance of strength, accuracy, and time for the intended application.

CONCLUSION

This study examined the influence of layer thickness, infill density, and orientation on the tensile strength and dimensional accuracy of fused deposition modelling parts. Tensile strength increased with infill density and finer layers, flat orientation gave the highest strength owing to favourable inter-layer bonding, and dimensional accuracy improved with thinner layers at the expense of longer build times.

The findings provide practical guidance for producing functional polymer components, demonstrating that strength and accuracy can be tuned within limits through informed parameter selection. Orientation, in particular, should be chosen so that loads act along the deposited layers.

LIMITATIONS

- A single thermoplastic material and one desktop machine were used.
- Only tensile strength was measured; other mechanical properties were not assessed.
- Environmental conditioning and long-term ageing of specimens were not considered.
- Build temperatures were fixed, so their interaction with other parameters was not studied.

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FUTURE SCOPE

- Evaluation of additional materials, including fibre-reinforced filaments.
- Assessment of flexural, impact, and fatigue properties.
- Study of the interaction between temperature and other process parameters.
- Use of statistical optimisation to balance strength, accuracy, and build time.
- Investigation of post-processing methods to improve inter-layer bonding.

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